COMMENT

Comments on "No-Tillage and Soil-Profile Carbon Sequestration: An On-Farm Assessment"

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Blanco-Canqui and Lal (2008) conducted a study to "…determine: (i) changes in SOC [soil organic carbon] within the topsoil due to conversion to NT [no tillage] farming, and (ii) the depth distribution (0–60 cm) of SOC in NT soils compared with PT [plow tillage] and forest soils." The authors pointed out the difficulties in interpreting the results of the farm-survey approach undertaken, especially regarding the difference in cropping history of each field site, difference in current crop management system since enrolled in a particular tillage system, difference in type of tillage implements, difference in fertilizer use, and difference in crop residue returned. All of these concerns are real, but the greater concern was the sampling approach, which should have tempered the strength of conclusions.

Only one field was sampled within a major land resource area (MLRA), and therefore, conventional statistical analysis should not have been used to assess the effects of management within a MLRA. A more appropriate choice of analysis should have been to use the 11 MLRA sampling locations as replicates for the three management systems (plow tillage, no tillage, and woodlot). Because multiple fields of a management system within a MLRA were not sampled, then the only valid comparison was of management systems across MLRAs. How management affects SOC within a MLRA (>1 Mha) should not have been based on three cores (40 cm^2) within a single field.

The data in Fig. 1 and 2 revealed striking differences between management systems, especially below 30 cm. For example, soil bulk density under woodlots from MLRA 140, 147, 139B, and 139C was much lower than under cropped soils below 30 cm, indicative of a vastly different landscape setting and/or soil type. Soil organic C was also much greater under woodlots at those depths than under cropped soils. By sampling only one field for each management system within a MLRA, the probability was high that the real effect of management on SOC storage would not be distinguishable from intrinsic variability; however without sufficient data, this distinction between sources of variation cannot be known.

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The calculation of SOC to a cumulative depth of 60 cm in Fig. 4 is not consistent with the data for bulk density and SOC reported in Fig. 1 and 2. Values in Fig. 4 are 4.5 ± 0.8-fold greater than values calculated from data in Fig. 1 and 2. This putative error in summation to a depth of 0 to 60 cm appears to have been perpetuated in Table 2 when reporting estimates for differences in SOC. Changes in SOC of >|2| Mg ha^{-1} yr^{-1} are phenomenal—these high values occurred in 8 of 11 cases. It is rare to see such large magnitudes of difference in the literature. The reported C loss rate of −5.2 ± 1.9 Mg ha^{-1} yr^{-1} in the four cases that were negative would be greater in magnitude than C accumulation rates in above-ground tree growth from temperate ecosystems. For example, fast-growing pine forests in Georgia accumulate C in aboveground biomass at a rate of ~4 Mg ha^{-1} yr^{-1} (www.gacarbon.org).

When considering the MLRA sampling as replicates for the effect of the three management systems, then the amount of C stored in soil would be as presented in Table 1 here. These data suggest that SOC was greater under NT than under PT in the surface 10 cm—consistent with the point made in the original paper. A point of contention, however, is the interpretation of what happened below this surface depth. Soil organic C at 10- to 30-cm depth was not numerically or statistically different between tillage systems, even though this would be the zone where residue C was likely preferentially deposited by inversion tillage operations. Soil organic C at 30- to 50-cm depth was not statistically different between tillage systems, but this was the zone that negated surface SOC accumulation with NT (at least from the experimental evidence). Statistical significance could not be declared between tillage systems, because of greater random variation with depth (coefficient of variation was 42% at 30–50 cm versus 19% at 0–10 cm). Technically, the only significant difference between tillage systems occurred at 0- to 10-cm depth; no difference between tillage systems occurred at 30- to 50-cm depth. Only because of greater random variation did the tillage effect on SOC disappear, not because of greater SOC under PT than under NT at lower depths.

In a news release posted by the *Soil Science Society of America Journal*, the authors are quoted as saying "future studies in SOC sequestration must be done by analyzing the soil profile to about 2-m depth rather than the surface layer only." This recommendation goes beyond the methods and scope of evaluation presented in this report. This recommendation should be reconsidered in light of the increasing random variation observed with depth. In fact, in a field study with repeated sampling in time in Georgia, for every additional 0.3 m of soil sampled below the plow layer (i.e., 30 cm), the change in SOC would have had to be 0.6 Mg ha^{-1} greater to maintain statistical significance between forage management means (Franzluebbers and Stuedemann, 2005). These data indicated that significant SOC sequestration with time could have only been detected with a difference of 3.2 Mg ha^{-1} at a depth of 0 to 0.3 m and only with a difference of 5.3 Mg ha^{-1} at a depth of 0 to 1.5 m. The implication from this study was that a much more rigorous sampling approach is needed [e.g., (i) repeated sampling with time, (ii) stratified sampling to account for known landscape variations, and (iii) numerous cores to collect to properly capture a true mean] to overcome natural variations in soil at lower depths.

Reasonable conclusions from the study of Blanco and Lal (2008) should have been limited to: (i) SOC storage was greater under NT than under PT only in the surface 10 cm on farmers' fields in the eastern Corn Belt (KY, OH, and PA) and (ii) greater random variation with increasing soil depth limited the possibility to declare differences in SOC and N storage between tillage systems.

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Table 1. Recalculated soil organic C values from data presented in Fig. 1 and 2 of Blanco-Canqui and Lal (2008). Statistical analysis was conducted to separate means among management systems using 11 fields from the major land resource areas as blocks.

Depth	Management System			Comments†
	Plow tillage (PT)	No tillage (NT)	Woodlot (WL)	
cm				
0–5	10.1	11.9	16.5	WL > NT = PT; $LSD_{0.05}$ = 2.4; CV = 21%
5–10	9.5	15.0	20.4	WL > NT > PT; $LSD_{0.05}$ = 3.3; CV = 25%
10–30	41.2	41.6	56.0	WL > NT = PT; $LSD_{0.05}$ = 10.8; CV = 26%
30–50	30.7	24.2	45.1	WL > PT = NT; $LSD_{0.05}$ = 12.6; CV = 42%
50–60	9.0	7.2	18.8	WL > PT = NT; $LSD_{0.05}$ = 6.0; CV = 58%
0–10	19.7	27.0	36.9	WL > NT > PT; $LSD_{0.05}$ = 4.6; CV = 19%
0–30	60.8	68.6	92.9	WL > NT = PT; $LSD_{0.05}$ = 13.5; CV = 20%
0–50	91.6	92.8	138.0	WL > NT = PT; $LSD_{0.05}$ = 22.8; CV = 24%
0–60	100.6	100.0	156.9	WL > PT = NT; $LSD_{0.05}$ = 27.0; CV = 25%

†LSD is least significant difference; CV is coefficient of variation.

RESPONSE

Response to the 'Comments on "No-Tillage and Soil-Profile Carbon Sequestration: An On-Farm Assessment"'

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Franzluebbers (2009) is right about the need for a more intensive soil sampling, "repeated sampling with time," and "stratified sampling" as well as for the use of multiple fields and collection of larger number of pseudoreplicates to overcome the high field variability in soil organic carbon (SOC) pools within each Major Land Resource Area (MLRA). The selected fields were representative of each MLRA in terms of soil type, slope, and management, but it is correct that a single soil would not capture all the variability in soil and management for the whole MLRA. This study was not intended to relate the data from the single soil to the whole MLRA but rather to emphasize the differences in SOC sequestration rates among the three management systems within each soil.

Franzluebbers (2009) also suggests that a better approach to analyze our data "should have been to use the 11 MLRAs sampling locations as replicates." Although his concern is pertinent in regards to sampling protocol, the approach he suggests is not appropriate for this regional study which comprised 11 sites with large and significant differences in soil-specific characteristics (e.g., texture and drainage), topography, management duration, tillage intensity, cropping systems, fertilization rates, and use of amendments (manure). These marked differences warranted an analysis of management effects by soil or MLRA. We also wish to reiterate that three soil samples at random points were collected within each of the three adjacent fields (no-till, plow tillage, and woodlot) in each MLRA. Because differences in soil textural class and landscapes attributes (slope, curvature, aspect) within each soil were similar among the three management systems, the three samples were used as pseudoreplicates and the experiment was treated as a completely randomized design. It is a fact that using pseudoreplication sacrifices any intrinsic differences that may exist among the three fields, but it is still a better approach than using MLRA as replicates.

We thank Franzluebbers (2009) and Boddey et al. (2009) for detecting our error in Fig. 4 and Column 6 in Table 2 for SOC pool values. The error involved not using mean values. We had mistakenly reported the summation of SOC values across the three replicates for each land use system rather than the means. The corrected Fig. 4 and Table 2 are reported below. Because of the error in calculation, changes in SOC pools were grossly exaggerated as noted by Franzluebbers (2009) and Boddey et al. (2009). We must also clarify that the mean N pools (Mg ha^{-1}) in Table 3 are reported for a constant soil depth of 5 cm within each of the five depth intervals. In accord with Boddey et al. (2009), we wish to state that the error in calculations does not, however, change the main conclusions of our study. The recalculated ΔSOC values differ from those by Boddey et al. (2009) because our ΔSOC values were computed for the 0 to 60 cm sampling depth using the five variable soil depth intervals (5, 5, 20, 20, and 10 cm) whereas the ΔSOC values by Boddey et al. (2009) were computed using the mean N pools reported for a constant soil depth of 5 cm for each of the five depth intervals.

In response to the Franzluebbers (2009) argument about not estimating the SOC pool to 2-m depth in the present study, the recommendation about the assessment to "at least 2 m depth" is also justified by the conclusion drawn from recent emerging literature (Puget and Lal, 2005; West and Post, 2002; VandenBygaart et al., 2003; Lorenz and Lal, 2005; Baker et al., 2007) discussing rates and implications of subsoil SOC sequestration. We agree with Franzluebbers (2009) that sophisticated sampling approaches and improved statistical tools must be used to deal with any large "random variations" of SOC with soil depth.

It is also important to stress the need of conducting more studies of this type to gain a broader understanding of no-till farming potential for SOC sequestration under on-farm conditions. Current database on SOC sequestration and understanding of no-till technology have been mostly derived from small research plots (West and Post, 2002). Results from these small plots while highly valuable for research purposes do not always reflect the complexity of no-till practices under on-farm conditions. Yet, these on-farm data on SOC sequestration in no-till are needed to develop not only a database for assessing tradable marketing C credits but also for determining the ancillary benefits of SOC sequestration to soil, agronomic production, and environmental quality. Finally, the data on the management-induced gains and losses of SOC (ΔSOC), reported in Table 2, would have been more robust and accurate should the data on antecedent SOC pools were also available for each management system within each soil. Without the initial SOC pools, changes in SOC due to management differences cannot be conclusively assessed. It is also naïve to assume that any practice, even the environmentally compatible and economically sound techniques such as no-till, is a panacea and can be effective in all soils in diverse edaphological conditions and social and political scenarios.

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Table 2. Differences in soil organic C (SOC) between no-tillage (NT) and plow tillage (PT) for the whole soil profile across a range of soils.

Site	Soil	Cropping System	Duration of NT	Total Depth of Sampling	ΔSOC† ($Mgha^{-1}$ yr^{-1})	Statistical Significance (NT vs. PT)	Reference
Londrina, Brazil	Clayey	Soybean–winter wheat and corn-soybean-cotton	21	40		NS‡	Machado et al. (2003)
Harrington, Canada	Fine sandy loam	Wheat-barley (Hordeum vulgare L.)/barley-soybean	8	60	−0.99	NS	Angers et al. (1997)
La Pocatière, Canada	Clay	Continuous barley	6	60	−3.38	NS	Angers et al. (1997)
Normandin-2, Canada	Silty clay	Continuous barley	3	60	0.90	NS	Angers et al. (1997)
Ottawa, Canada	Sandy loam	Continuous corn	5	60	1.20	NS	Angers et al. (1997)
Ottawa, Canada	Sandy loam	Continuous wheat	5	60	2.97	NS	Angers et al. (1997)
Delhi, Canada	Sandy loam	Continuous corn	4	60	−0.77	NS	Angers et al. (1997)
Harrow, Canada	Clay loam	Continuous corn	11	60	−0.08	NS	Angers et al. (1997)
Ponta Grossa, Brazil	Clay	Wheat-soybean/black oat (Avena strigosa Schreb.) soybean/black oat-corn	22	40	0.86	S§	Sa et al. (2001)
Prince Edward Island, Canada	Fine sandy loam	Soybean-barley	16	60	−0.20 (estimate)	NS	Carter (2005)
Waseca, MN	Clay loam	Continuous corn	14	45	1.9	S	Huggins et al. (2007)
Waseca, MN	Clay loam	Continuous soybean	14	45	0.85	NS	Huggins et al. (2007)
Waseca, MN	Clay loam	Corn-soybean	14	45	0.76	NS	Huggins et al. (2007)
Rosemount, MN	Silt loam	Corn-soybean with corn stover removed	23	45	0	NS	Dolan et al. (2006)
Rosemount, MN	Silt loam	Corn-soybean with corn stover returned	23	45	−0.48	NS	Dolan et al. (2006)
Ontario, Canada	Silt loam	Continuous corn	29	50	−0.04	NS	Wanniarachchi et al. (1999)
MLRA 121 (Georgetown, KY)	Silt loam	Sweet corn-soybean- pumpkin and corn-soybeans-vegetables	8	60	0.74	NS	This study
MLRA 122 (Glasgow, KY)	Silt loam	Corn-soybean and corn-soybean-tobacco	10	60	0.91	NS	This study
MLRA 125 (McKee, KY)	Silt loam	Continuous corn silage and continuous tobacco and wheat and rye cover crop	15	60	−2.96	S	This study
MLRA 99 (Fremont, OH)	Silty clay loam	Corn-soybean	15	60	−1.58	S	This study
MLRA 124 (Jackson, OH)	Silt loam	Corn-soybean-alfalfa and continuous corn	12	60	−2.24	S	This study
MLRA 139A (Canal Fulton, OH)	Loam	Corn-soybean	30	60	1.21	NS	This study
MLRA 139B (Grove City, PA)	Silt loam	Corn-soybean	10	60	1.60	NS	This study
MLRA 139C (Greenville, PA)	Silt loam	Corn-soybean	8	60	−0.98	NS	This study
MLRA 140 (Troy, PA)	Loam	Continuous corn	20	60	0.74	NS	This study
MLRA 147 (Lewisburg, PA)	Silt loam	Corn-soybean	5	60	0.63	NS	This study
MLRA 148 (Mount Joy, PA)	Clay loam	Corn-soybean-alfalfa and continuous corn	4	60	0.61	NS	This study

† ΔSOC = SOC in NT-SOC in PT.
‡ NS = Nonsignificant.
§ S = Significant.

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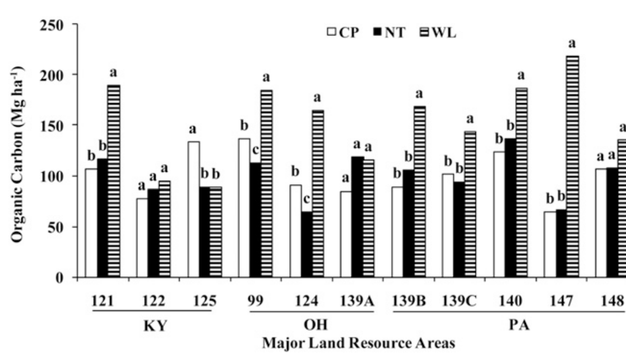

Fig. 4. Mean soil organic carbon concentration on an area basis for the whole soil profile (0- to 60- cm) for no-tillage (NT), plow tillage (PT), and woodlot (WL) management within each selected Major Land Resource Area across KY, OH, and PA. Error bars are the LSD values for each depth interval.